US005838588A

# United States Patent [19]

Santoso et al.

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[45] Date of Patent: Nov. 17, 1998

[54] **GRAPHICAL USER INTERFACE SYSTEM FOR STEAM TURBINE OPERATING CONDITIONS**

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[21] Appl. No.: **768,047**

[22] Filed: **Dec. 13, 1996**

[51] **Int. Cl.**[6] ..... **G05B 15/00**

[52] **U.S. Cl.** ..... **304/528.22**; 364/468.03; 364/468.01; 364/528.25

[58] **Field of Search** ..... 364/557, 468.03, 364/468.04, 468.01, 528.22, 528.25; 345/145, 146, 340, 428, 915, 919, 920, 921, 970, 339

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*Primary Examiner*—Louis M. Arana

*Assistant Examiner*—Hien Vo

*Attorney, Agent, or Firm*—Adel A. Ahmed

[57] **ABSTRACT**

A graphical user interface provides a real-time information display for a supervising engineer in charge of turbine operation so that critical parameter values and undesirable combinations of operating conditions are readily observed and deviations are made apparent so that corrective action can be initiated rapidly. An overview of the operating situation is made more readily apparent by representing the operating expansion and compression processes by lines on a Mollier enthalpy/entropy chart. In combination, real-time parameter values and parameter trends are also presented. Using the Mollier chart information in conjunction with trend and real-time information, the supervising engineer can more quickly identify and correct undesirable and potentially troublesome operation conditions.

**8 Claims, 14 Drawing Sheets**

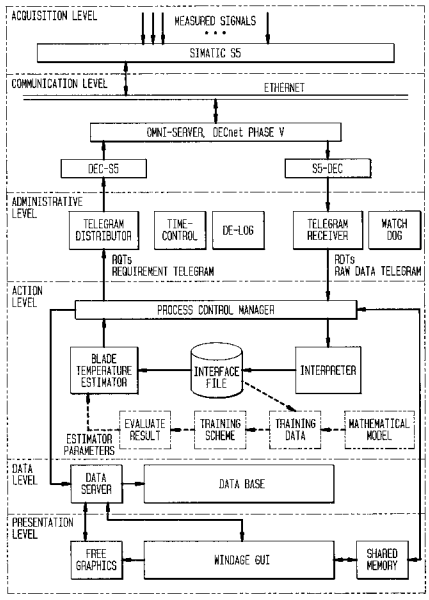


FIG. 1

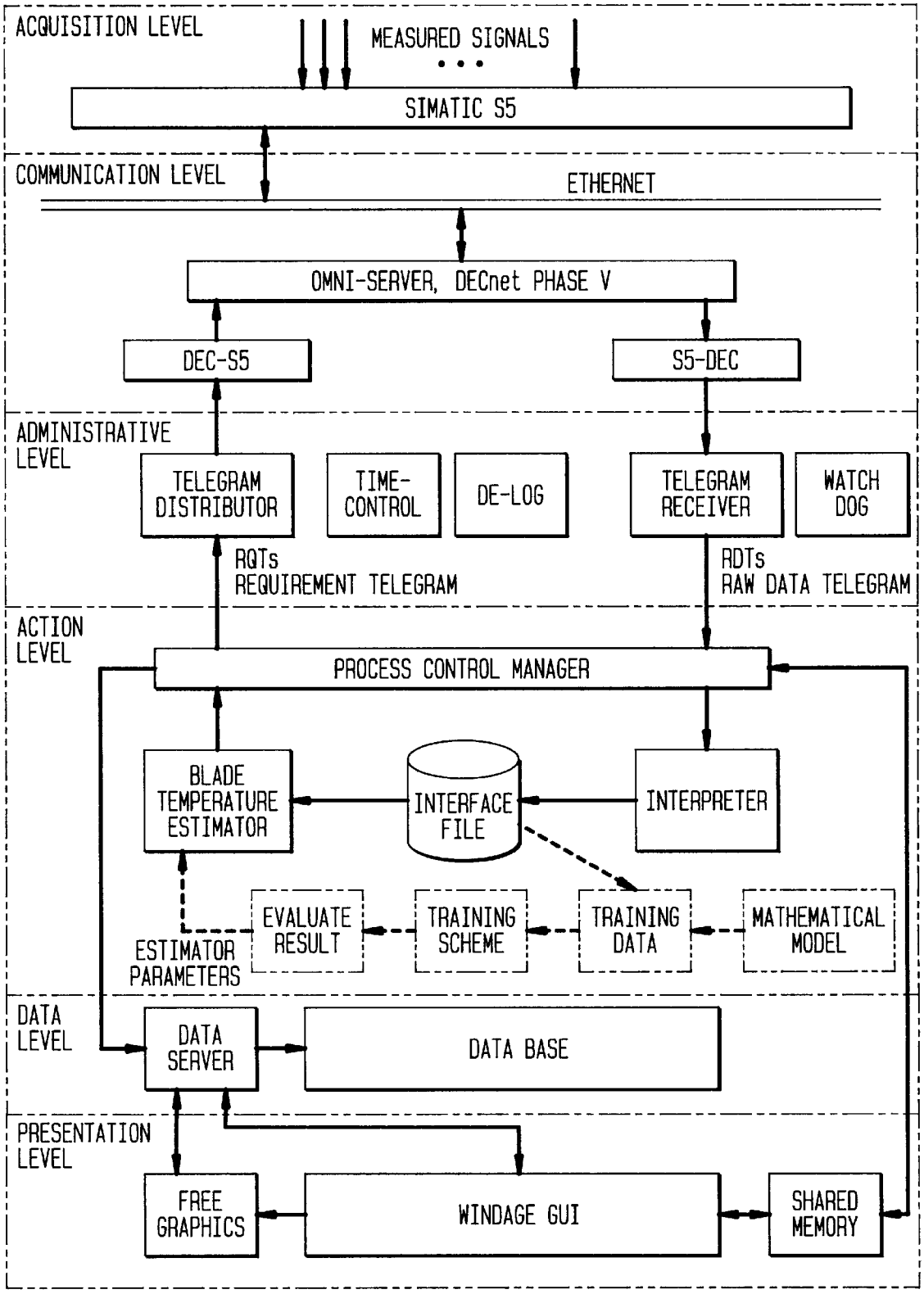

ACQUISITION LEVEL
MEASURED SIGNALS
SIMATIC S5
COMMUNICATION LEVEL
ETHERNET
OMNI-SERVER, DECnet PHASE V
DEC-S5
S5-DEC
ADMINISTRATIVE LEVEL
TELEGRAM DISTRIBUTOR
TIME-CONTROL
DE-LOG
TELEGRAM RECEIVER
WATCH DOG
RQTs REQUIREMENT TELEGRAM
RDTs RAW DATA TELEGRAM
ACTION LEVEL
PROCESS CONTROL MANAGER
BLADE TEMPERATURE ESTIMATOR
INTERFACE FILE
INTERPRETER
ESTIMATOR PARAMETERS
EVALUATE RESULT
TRAINING SCHEME
TRAINING DATA
MATHEMATICAL MODEL
DATA LEVEL
DATA SERVER
DATA BASE
PRESENTATION LEVEL
FREE GRAPHICS
WINDAGE GUI
SHARED MEMORY

FIG. 2A

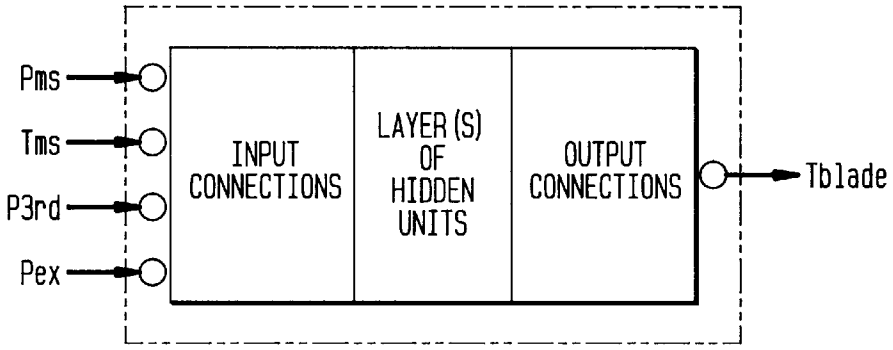

Pms
Tms
P3rd
Pex
INPUT CONNECTIONS
LAYER (S) OF HIDDEN UNITS
OUTPUT CONNECTIONS
Tblade

FIG. 2B

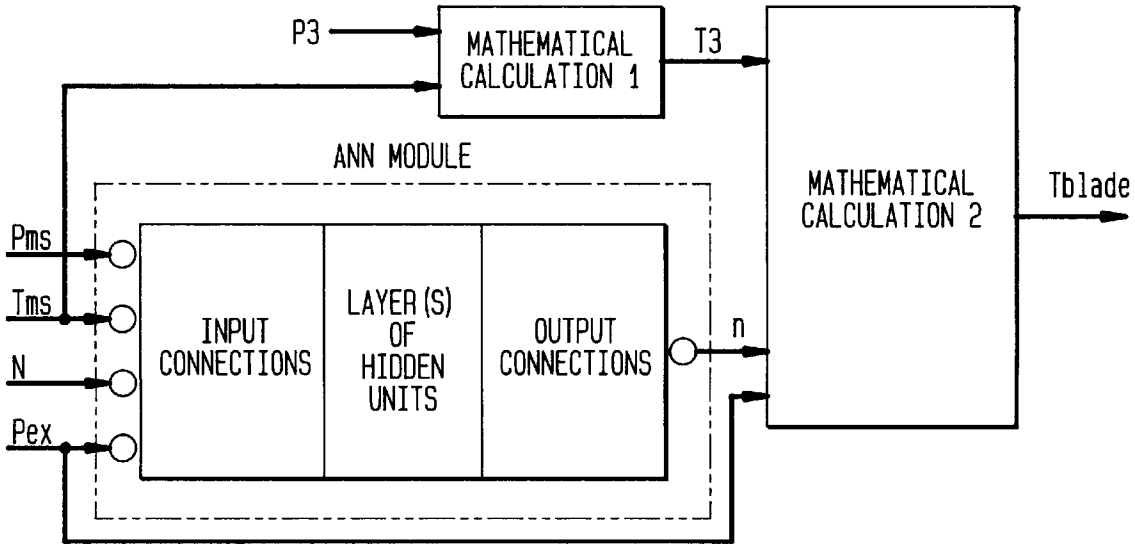

P3
MATHEMATICAL CALCULATION 1
T3
ANN MODULE
Pms
Tms
N
Pex
INPUT CONNECTIONS
LAYER (S) OF HIDDEN UNITS
OUTPUT CONNECTIONS
n
MATHEMATICAL CALCULATION 2
Tblade

FIG. 3

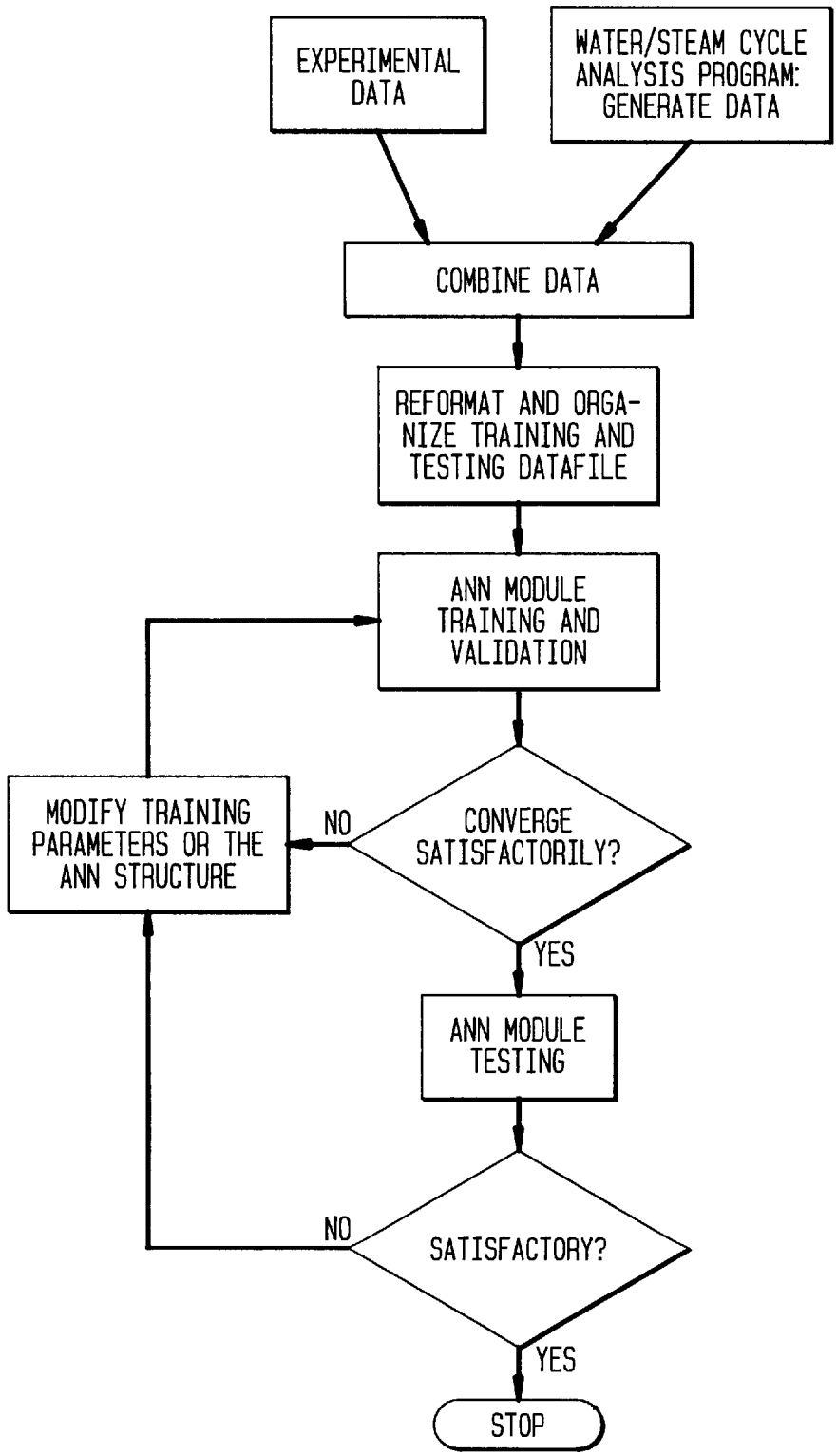

EXPERIMENTAL DATA
WATER/STEAM CYCLE ANALYSIS PROGRAM: GENERATE DATA
COMBINE DATA
REFORMAT AND ORGA-NIZE TRAINING AND TESTING DATAFILE
ANN MODULE TRAINING AND VALIDATION
CONVERGE SATISFACTORILY?
NO
MODIFY TRAINING PARAMETERS OR THE ANN STRUCTURE
YES
ANN MODULE TESTING
SATISFACTORY?
NO
YES
STOP

FIG. 4A

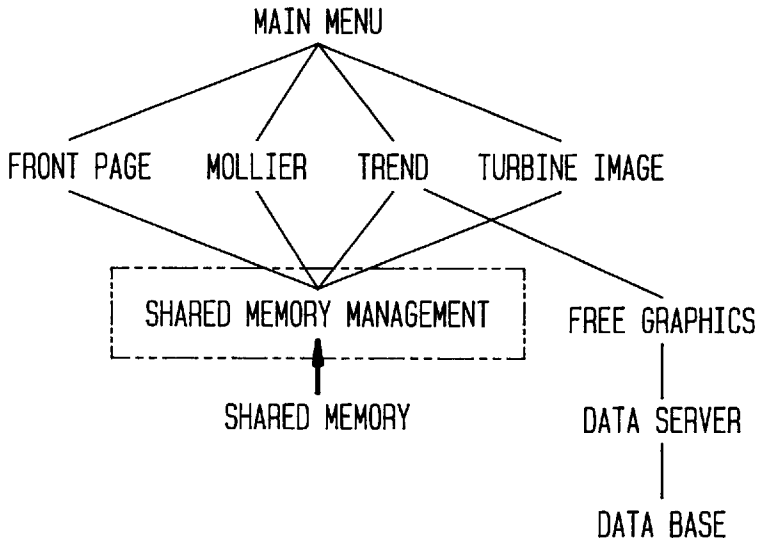

MAIN MENU
FRONT PAGE
MOLLIER
TREND
TURBINE IMAGE
SHARED MEMORY MANAGEMENT
FREE GRAPHICS
SHARED MEMORY
DATA SERVER
DATA BASE

FIG. 4B

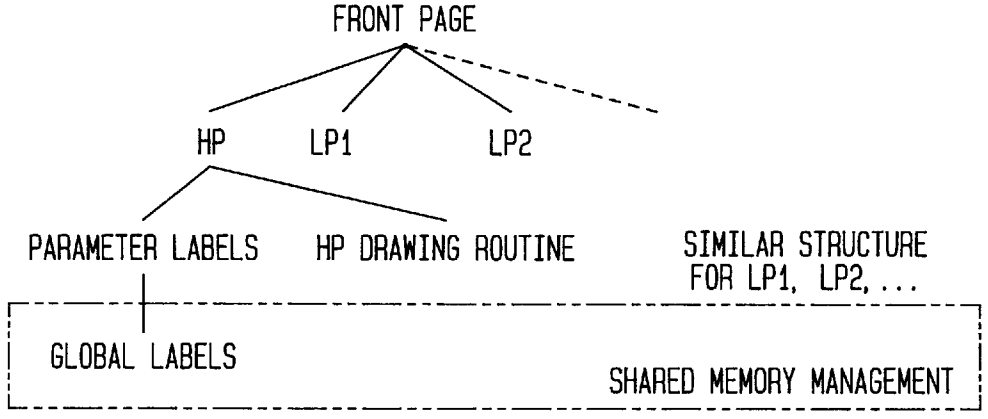

FRONT PAGE
HP
LP1
LP2
PARAMETER LABELS
HP DRAWING ROUTINE
SIMILAR STRUCTURE FOR LP1, LP2, ...
GLOBAL LABELS
SHARED MEMORY MANAGEMENT

FIG. 4C

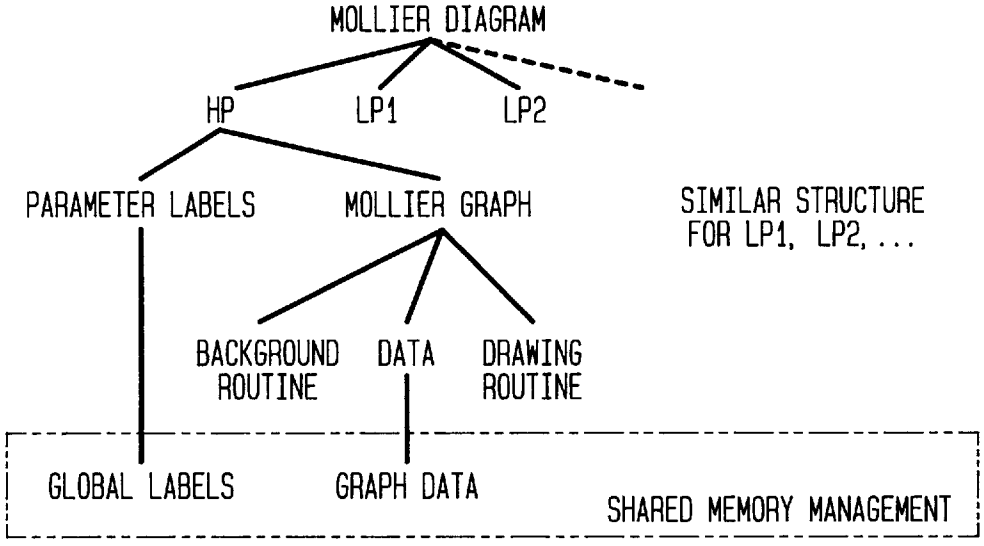
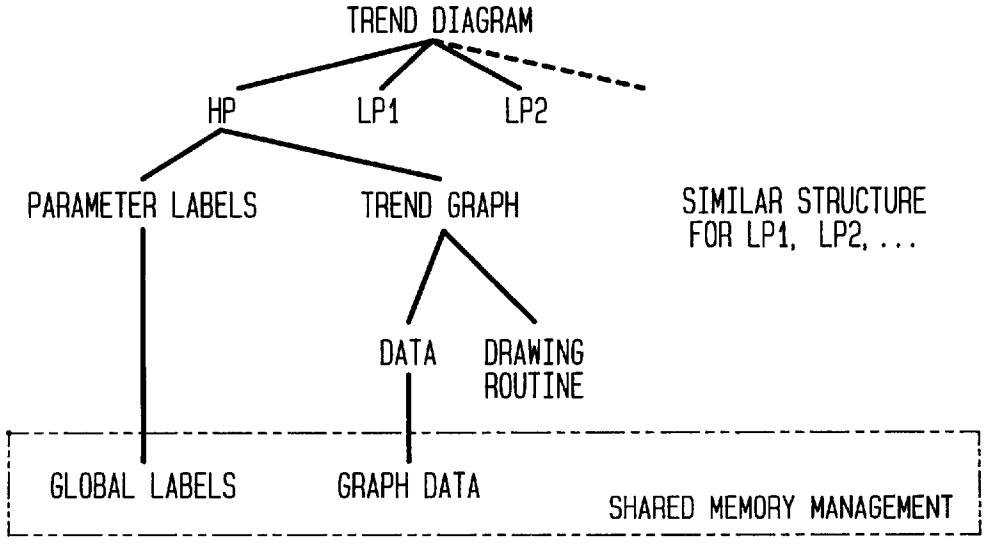

MOLLIER DIAGRAM
HP
LP1
LP2
PARAMETER LABELS
MOLLIER GRAPH
SIMILAR STRUCTURE FOR LP1, LP2, ...
BACKGROUND ROUTINE
DATA
DRAWING ROUTINE
GLOBAL LABELS
GRAPH DATA
SHARED MEMORY MANAGEMENT

FIG. 4D


TREND DIAGRAM
HP
LP1
LP2
PARAMETER LABELS
TREND GRAPH
SIMILAR STRUCTURE FOR LP1, LP2, ...
DATA
DRAWING ROUTINE
GLOBAL LABELS
GRAPH DATA
SHARED MEMORY MANAGEMENT

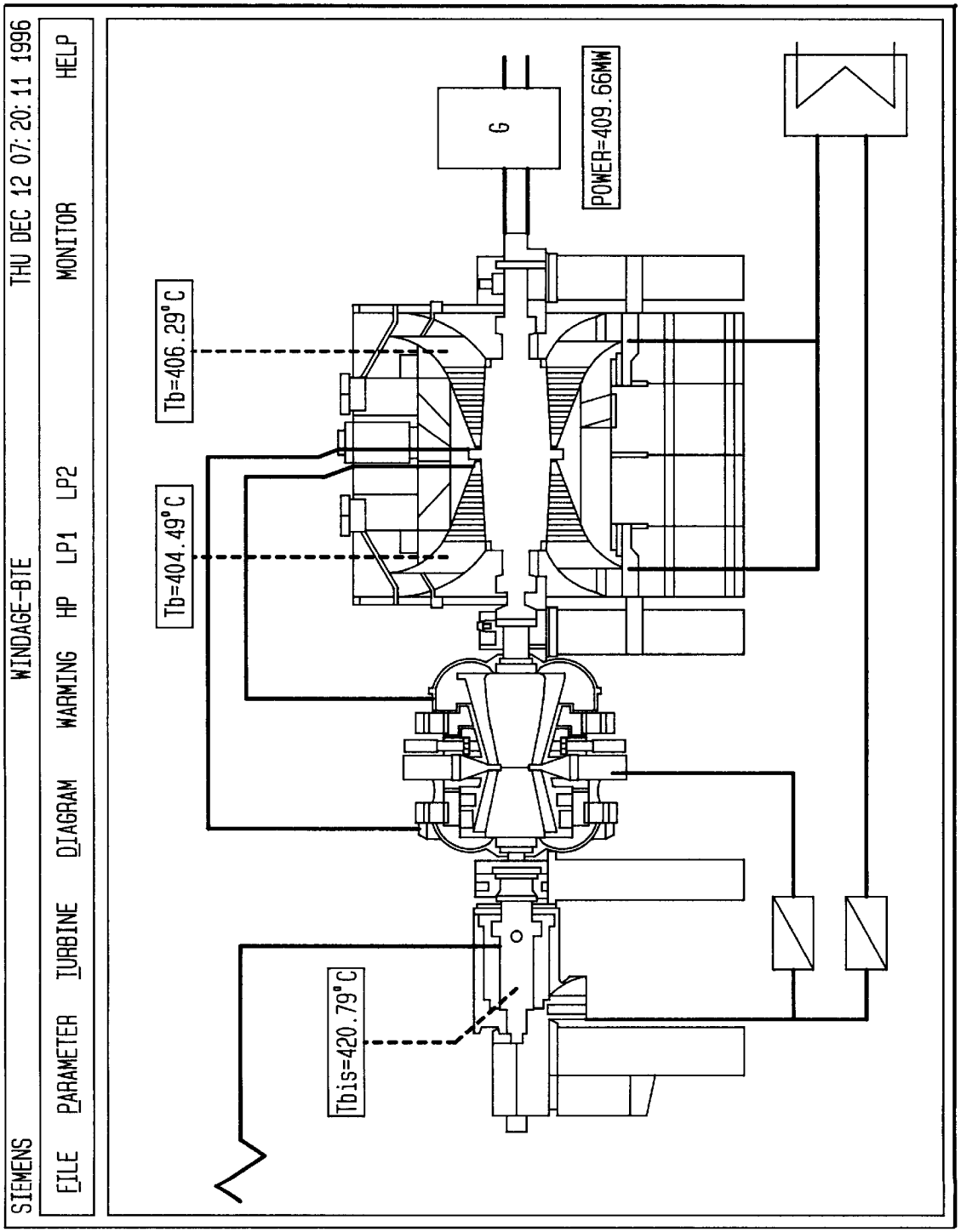

SIEMENS
WINDAGE-BTE
THU DEC 12 07:20:11 1996
FILE PARAMETER TURBINE DIAGRAM WARMING HP LP1 LP2 MONITOR HELP
6
POWER=409.66MW
Tb=406.29°C
Tb=404.49°C
Tbis=420.79°C

FIG. 5A

FIG. 5B

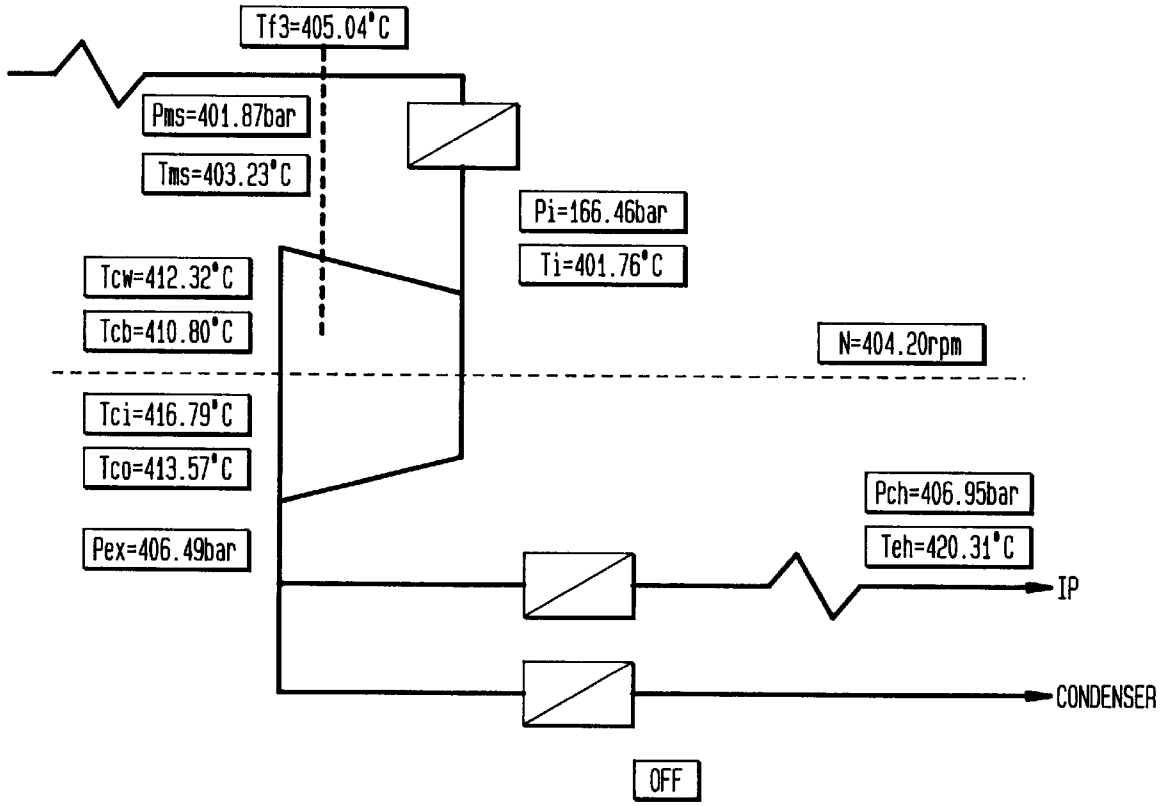

Tf3=405.04°C
Pms=401.87bar
Tms=403.23°C
Pi=166.46bar
Ti=401.76°C
Tcw=412.32°C
Tcb=410.80°C
N=404.20rpm
Tci=416.79°C
Tco=413.57°C
Pch=406.95bar
Teh=420.31°C
Pex=406.49bar
IP
CONDENSER
OFF

FIG. 5C

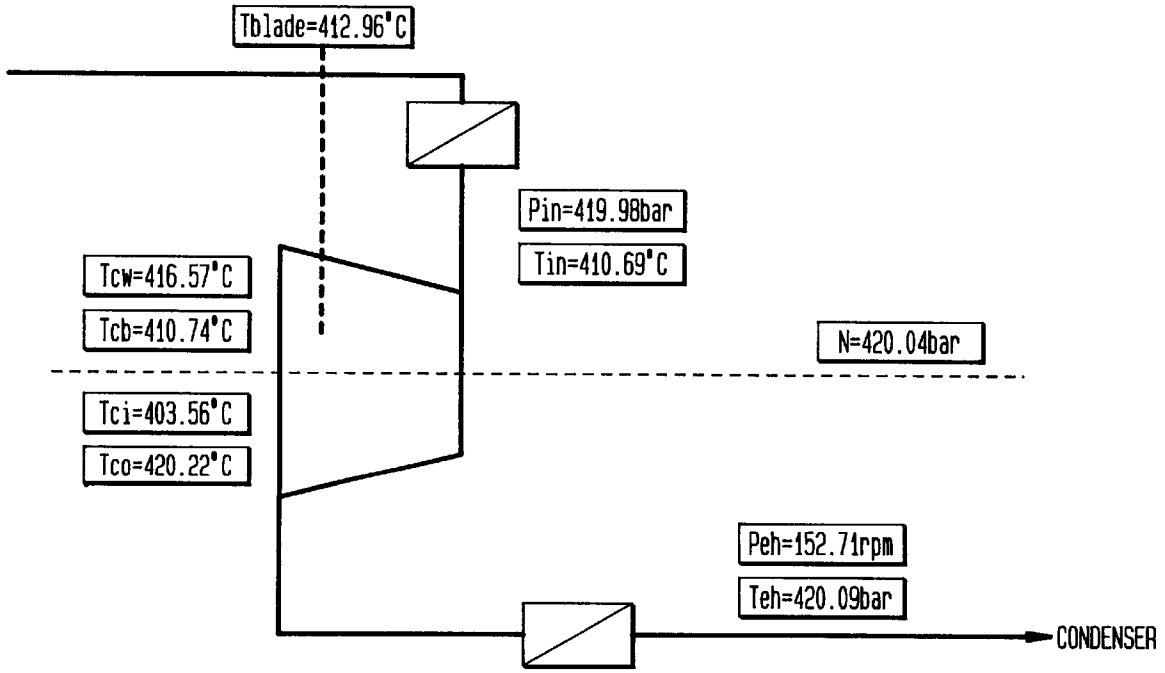
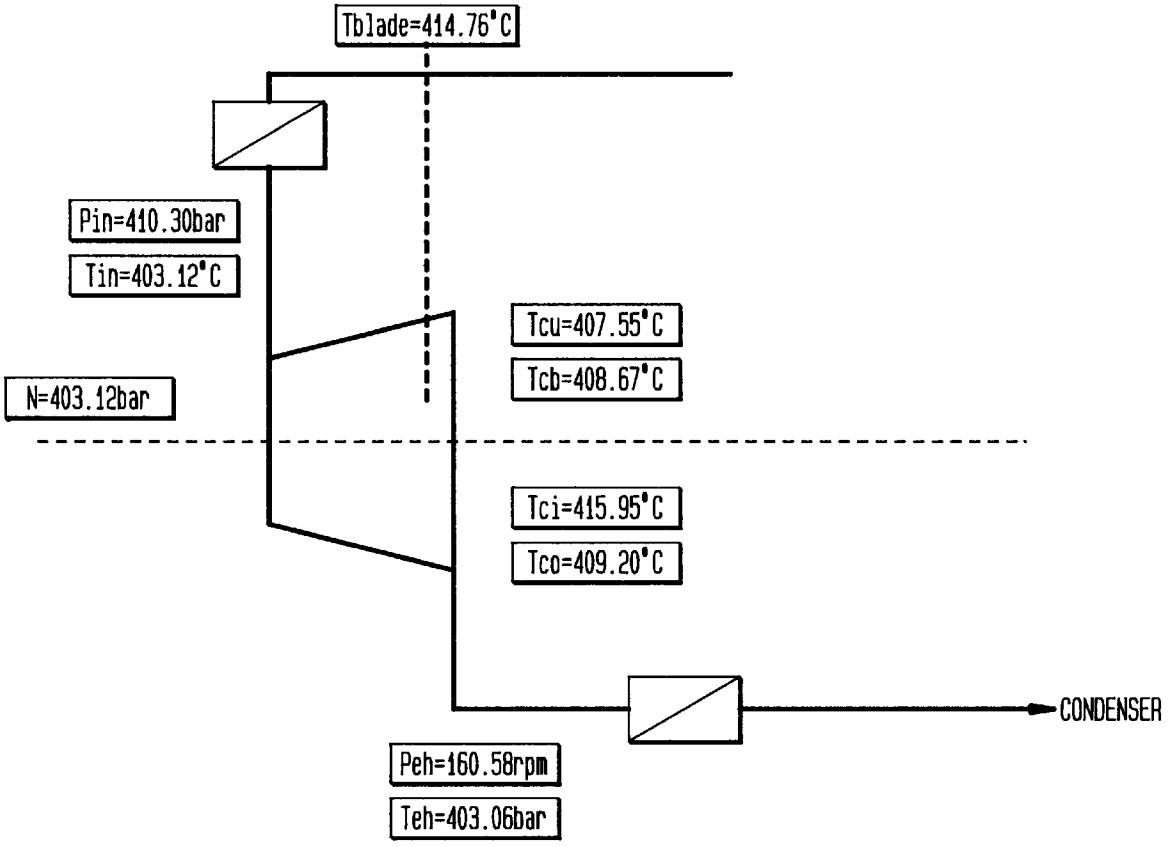

Tblade=412.96°C
Pin=419.98bar
Tin=410.69°C
Tcw=416.57°C
Tcb=410.74°C
N=420.04bar
Tci=403.56°C
Tco=420.22°C
Peh=152.71rpm
Teh=420.09bar
CONDENSER

FIG. 5D


Tblade=414.76°C
Pin=410.30bar
Tin=403.12°C
Tcu=407.55°C
Tcb=408.67°C
N=403.12bar
Tci=415.95°C
Tco=409.20°C
CONDENSER
Peh=160.58rpm
Teh=403.06bar

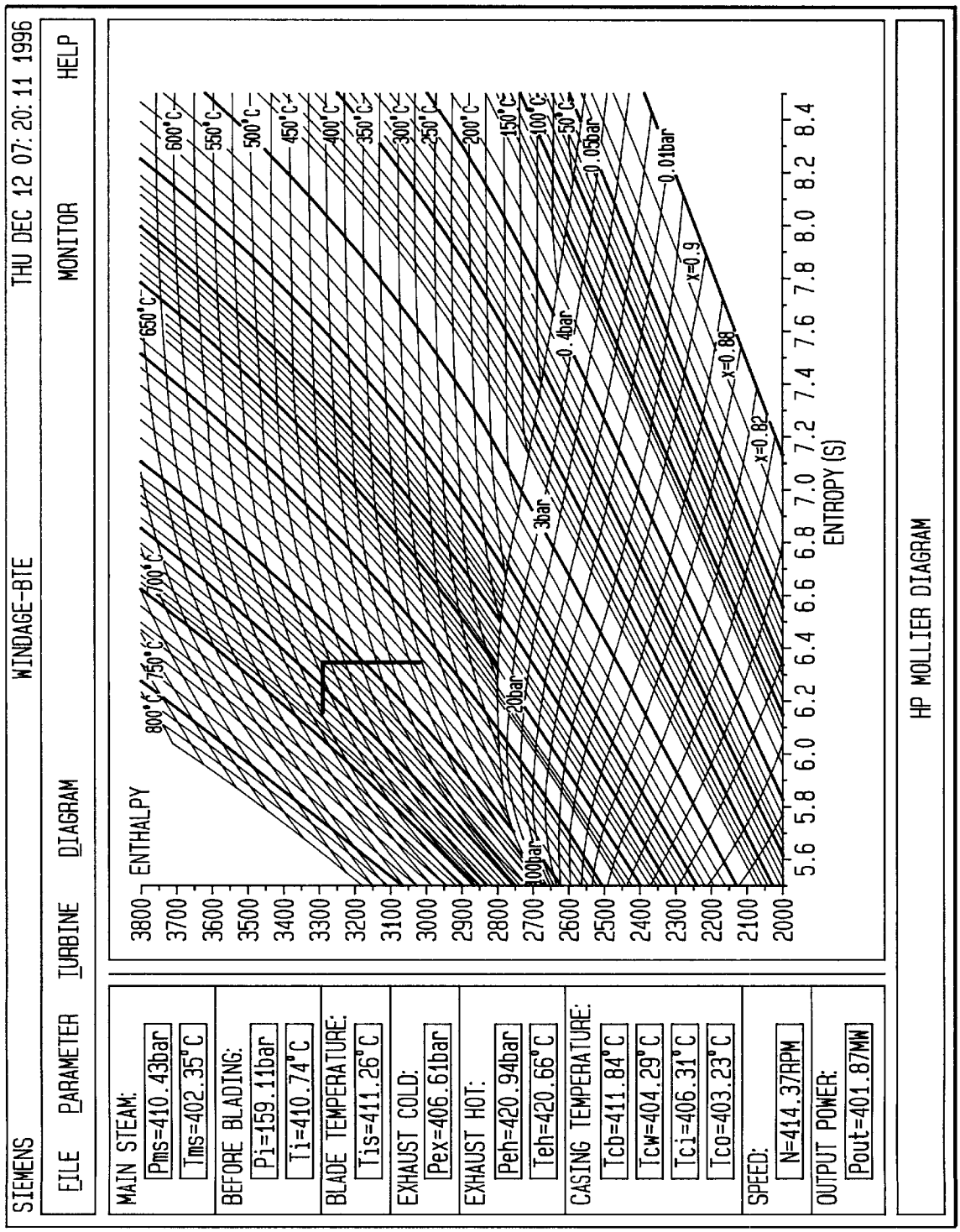

SIEMENS
WINDAGE-BTE
THU DEC 12 07:20:11 1996
FILE PARAMETER TURBINE DIAGRAM
MONITOR HELP
MAIN STEAM:
Pms=410.43bar
Tms=402.35°C
BEFORE BLADING:
Pi=159.11bar
Ti=410.74°C
BLADE TEMPERATURE:
Tis=411.26°C
EXHAUST COLD:
Pex=406.61bar
EXHAUST HOT:
Peh=420.94bar
Teh=420.66°C
CASING TEMPERATURE:
Tcb=411.84°C
Tcw=404.29°C
Tci=406.31°C
Tco=403.23°C
SPEED:
N=414.37RPM
OUTPUT POWER:
Pout=401.87MW
ENTHALPY
ENTROPY (S)
800°C
750°C
700°C
650°C
600°C
550°C
500°C
450°C
400°C
350°C
300°C
250°C
200°C
150°C
100°C
50°C
100bar
20bar
3bar
0.4bar
0.05bar
0.01bar
x=0.9
x=0.88
x=0.82
HP MOLLIER DIAGRAM

FIG. 5E

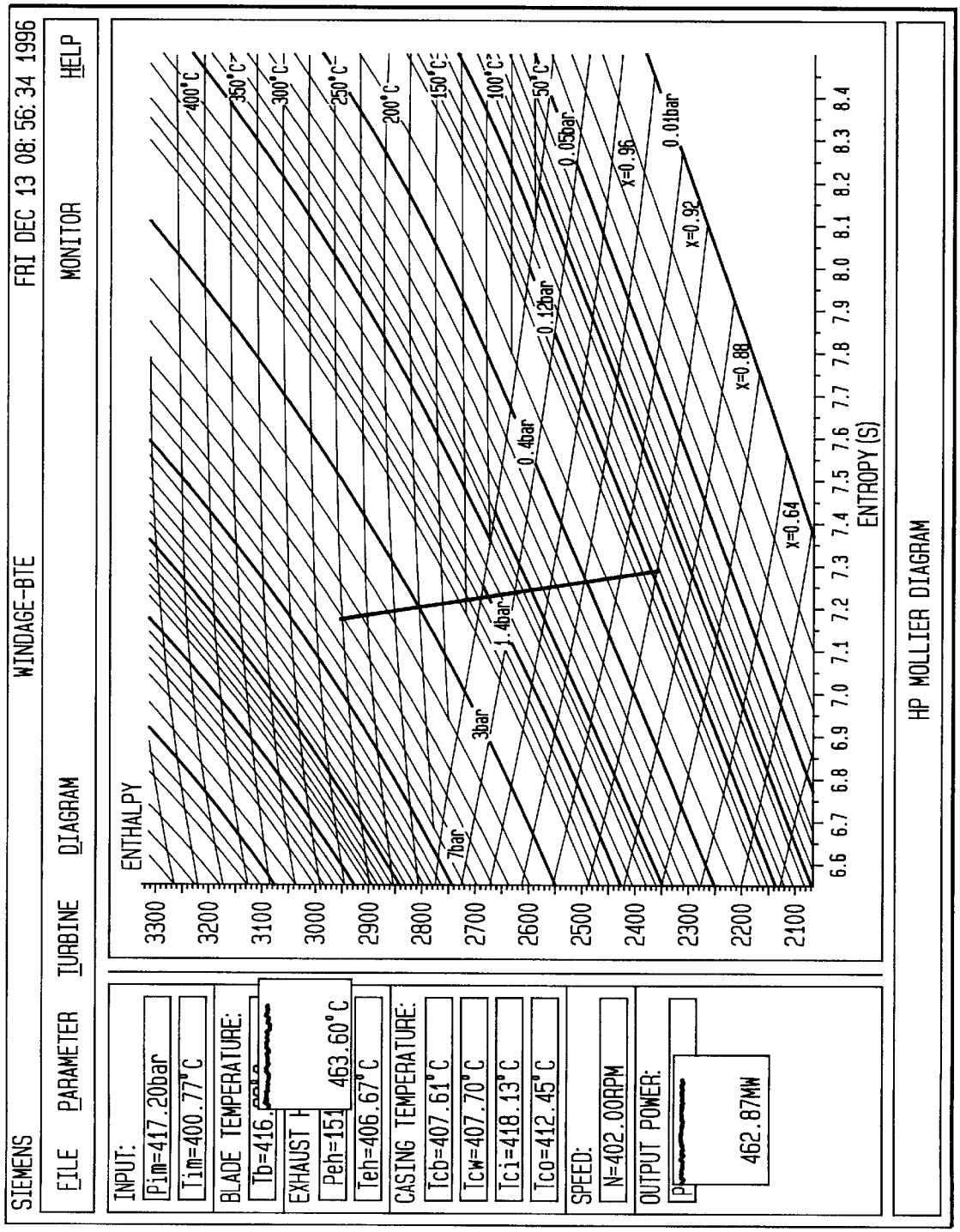

SIEMENS
WINDAGE-BTE
FRI DEC 13 08:56:34 1996
FILE PARAMETER TURBINE DIAGRAM
MONITOR HELP
INPUT:
Pim=417.20bar
Tim=400.77°C
BLADE TEMPERATURE:
Tb=416.
EXHAUST H
Peh=151
463.60°C
Teh=406.67°C
CASING TEMPERATURE:
Tcb=407.61°C
Tcw=407.70°C
Tci=418.13°C
Tco=412.45°C
SPEED:
N=402.00RPM
OUTPUT POWER:
462.87MW
ENTHALPY
3300
3200
3100
3000
2900
2800
2700
2600
2500
2400
2300
2200
2100
400°C
350°C
300°C
250°C
200°C
150°C
100°C
50°C
7bar
3bar
1.4bar
0.4bar
0.12bar
0.05bar
0.01bar
x=0.96
x=0.92
x=0.88
x=0.64
6.6 6.7 6.8 6.9 7.0 7.1 7.2 7.3 7.4 7.5 7.6 7.7 7.8 7.9 8.0 8.1 8.2 8.3 8.4
ENTROPY(S)
HP MOLLIER DIAGRAM

FIG. 5F

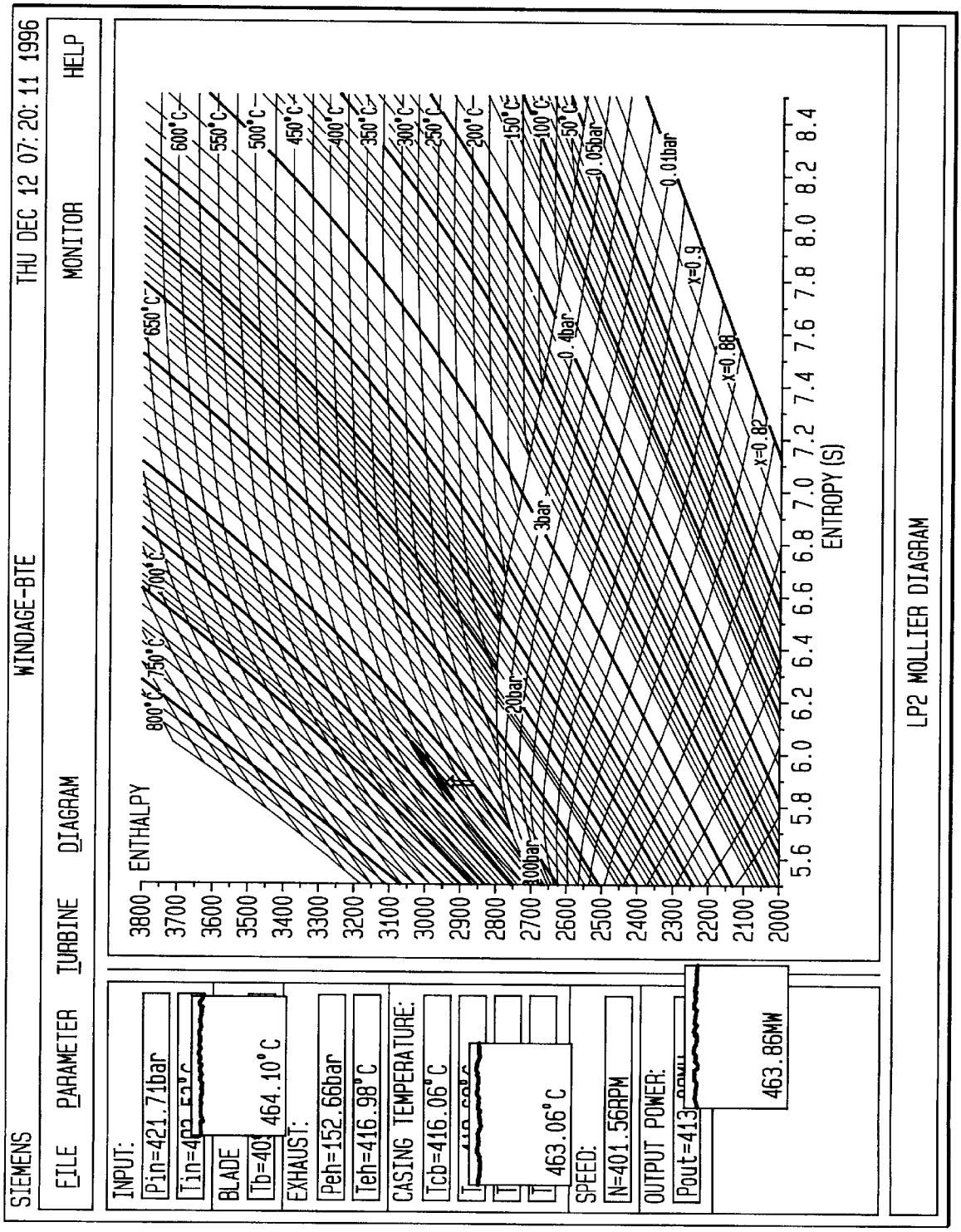

SIEMENS
WINDAGE-BTE
THU DEC 12 07:20:11 1996
FILE PARAMETER TURBINE DIAGRAM
MONITOR
HELP
INPUT:
Pin=421.71bar
Tin=4
BLADE
Tb=40
464.10°C
EXHAUST:
Peh=152.66bar
Teh=416.98°C
CASING TEMPERATURE:
Tcb=416.06°C
463.06°C
SPEED:
N=401.56RPM
OUTPUT POWER:
Pout=413
463.86MW
ENTHALPY
3800
3700
3600
3500
3400
3300
3200
3100
3000
2900
2800
2700
2600
2500
2400
2300
2200
2100
2000
800°C
750°C
700°C
650°C
600°C
550°C
500°C
450°C
400°C
350°C
300°C
250°C
200°C
150°C
100°C
50°C
100bar
20bar
3bar
0.4bar
0.05bar
0.01bar
x=0.9
x=0.88
x=0.82
5.6 5.8 6.0 6.2 6.4 6.6 6.8 7.0 7.2 7.4 7.6 7.8 8.0 8.2 8.4
ENTROPY (S)
LP2 MOLLIER DIAGRAM

FIG. 5G

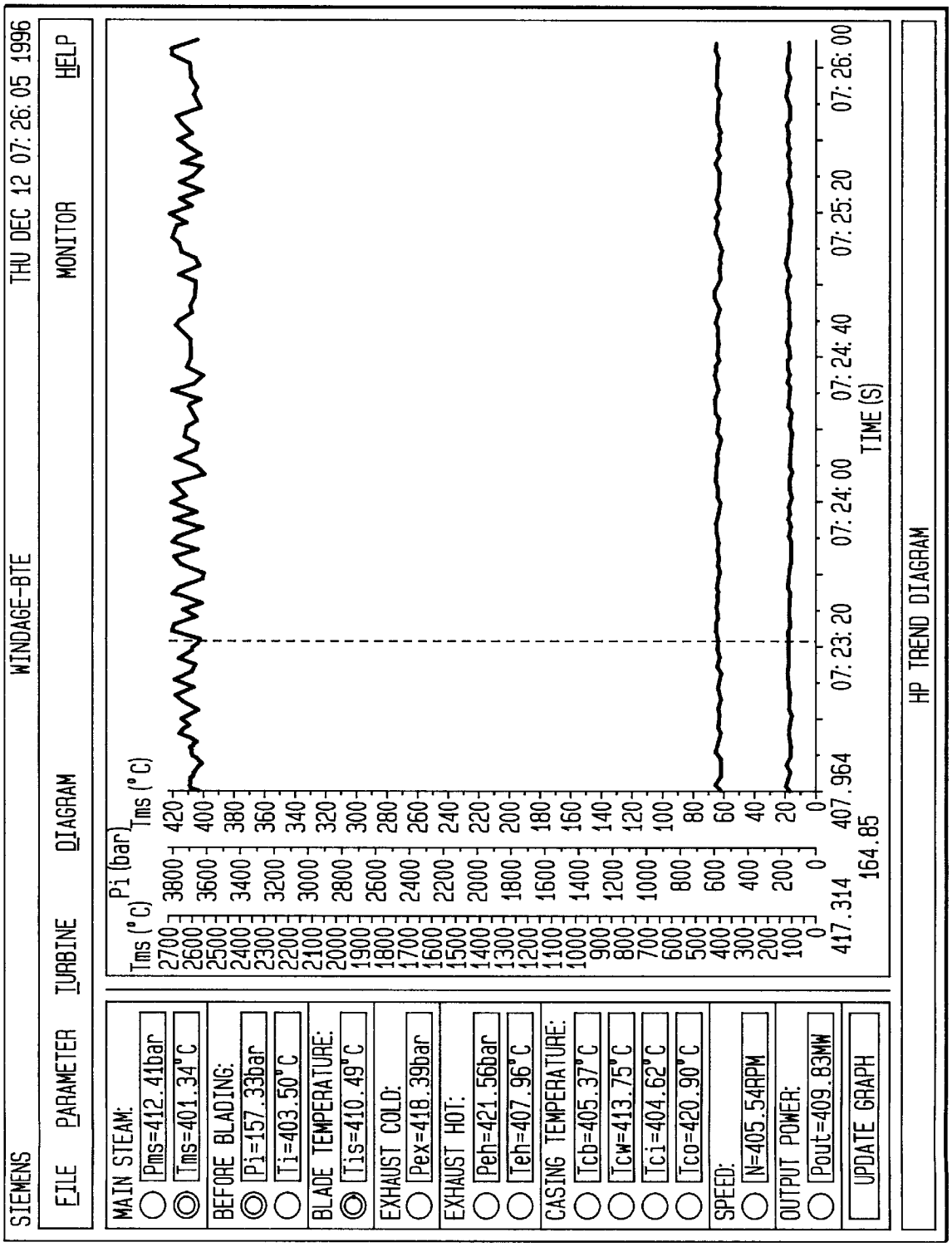

SIEMENS
WINDAGE-BTE
THU DEC 12 07: 26: 05 1996
FILE PARAMETER TURBINE DIAGRAM
MONITOR HELP
MAIN STEAM:
Pms=412.41bar
Tms=401.34°C
BEFORE BLADING:
Pi=157.33bar
Ti=403.50°C
BLADE TEMPERATURE:
Tis=410.49°C
EXHAUST COLD:
Pex=418.39bar
EXHAUST HOT:
Peh=421.56bar
Teh=407.96°C
CASING TEMPERATURE:
Tcb=405.37°C
Tcw=413.75°C
Tci=404.62°C
Tco=420.90°C
SPEED:
N=405.54RPM
OUTPUT POWER:
Pout=409.83MW
UPDATE GRAPH
Tms (°C)
Pi (bar)
Tms (°C)
TIME (S)
417.314
407.964
164.85
07: 23: 20
07: 24: 00
07: 24: 40
07: 25: 20
07: 26: 00
HP TREND DIAGRAM

FIG. 5H

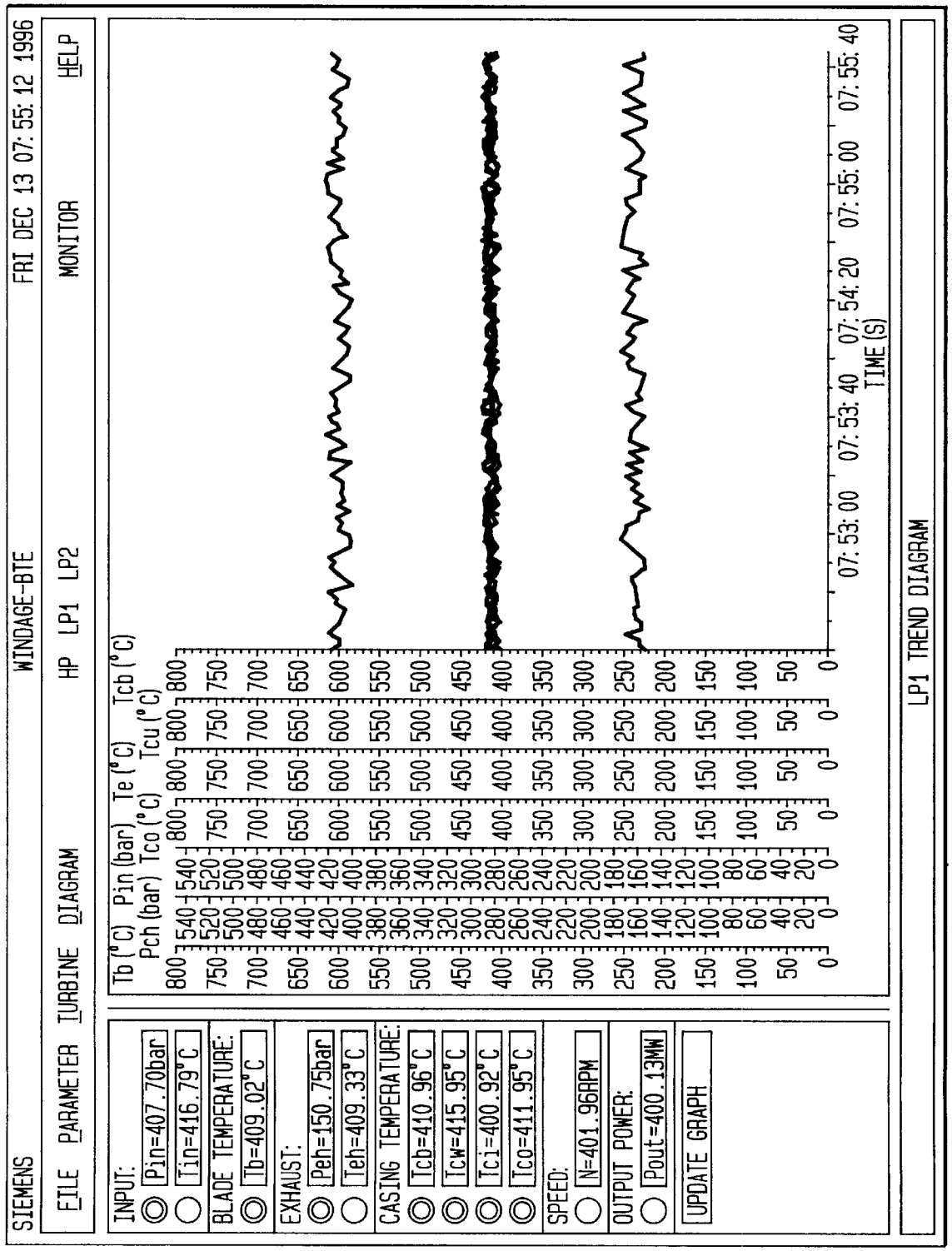

SIEMENS
WINDAGE-BTE
FRI DEC 13 07: 55: 12 1996
FILE PARAMETER TURBINE DIAGRAM
HP LP1 LP2
MONITOR
HELP
INPUT:
Pin=407.70bar
Tin=416.79°C
BLADE TEMPERATURE:
Tb=409.02°C
EXHAUST:
Peh=150.75bar
Teh=409.33°C
CASING TEMPERATURE:
Tcb=410.96°C
Tcw=415.95°C
Tci=400.92°C
Tco=411.95°C
SPEED:
N=401.96RPM
OUTPUT POWER:
Pout=400.13MW
UPDATE GRAPH
Tb (°C) Pin (bar) Te (°C) Tcb (°C)
Pch (bar) Tco (°C) Tcu (°C)
07: 53: 00
07: 53: 40
07: 54: 20
07: 55: 00
07: 55: 40
TIME (S)
LP1 TREND DIAGRAM

FIG. 5I

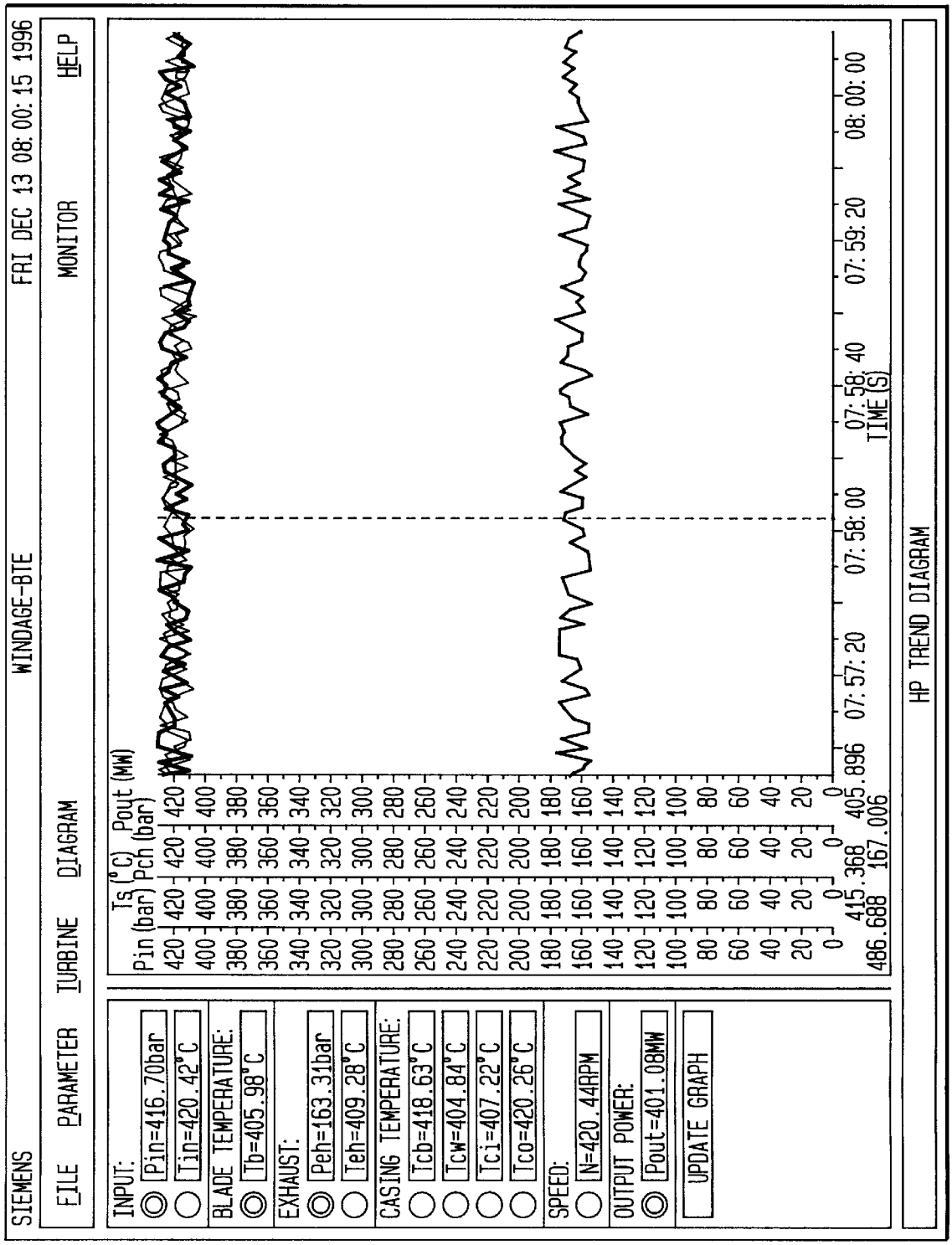

SIEMENS
WINDAGE-BTE
FRI DEC 13 08:00:15 1996
FILE PARAMETER TURBINE DIAGRAM
MONITOR HELP
INPUT:
Pin=416.70bar
Tin=420.42°C
BLADE TEMPERATURE:
Tb=405.98°C
EXHAUST:
Peh=163.31bar
Teh=409.28°C
CASING TEMPERATURE:
Tcb=418.63°C
Tcw=404.84°C
Tci=407.22°C
Tco=420.26°C
SPEED:
N=420.44RPM
OUTPUT POWER:
Pout=401.08MW
UPDATE GRAPH
Ts (°C) Pout (MW)
Pin (bar) Pch (bar)
420 400 380 360 340 320 300 280 260 240 220 200 180 160 140 120 100 80 60 40 20 0
486.688 415.368 167.006 405.896
07:57:20 07:58:00 07:58:40 07:59:20 08:00:00
TIME(S)
HP TREND DIAGRAM

FIG. 5J

# GRAPHICAL USER INTERFACE SYSTEM FOR STEAM TURBINE OPERATING CONDITIONS

In the operation of steam turbines, as for turbo-generators, it is important that operating parameters be kept within defined limits for proper and safe operation, including start-up and shut-down phases. Unsafe operation can have grave consequences for personal injury and material damage.

Reference is hereby made to an application by the present inventors being filed concurrently herewith and entitled A METHOD FOR BLADE TEMPERATURE ESTIMATION IN A STEAM TURBINE (Ser. No. 08/764,381) whereof the disclosure is incorporated herein to the extent it does not conflict with the present application.

Typically, in steam turbo-generator operations, the turbine was operated around full power or, when the demand for power was insufficient, it was shut down. Particularly in operation as part of a large power grid, operation at less than full load may be required. Under such conditions, complex patterns of temperature, pressure, steam wetness, reheating, expansion and compression, may occur, possibly resulting in excessive turbine blade temperature. Such conditions may spell blade failure with possibly disastrous consequences. Thus, monitoring operation under conditions where the intake steam pressure is at or lower than the output pressure are of practical importance. Background material is available in books such as W. W. Bathie, "Fundamentals of gas turbines", John Wiley and Sons, 1996; and H. Herlock, "Axial flow turbines: Fluid mechanics and thermodynamics", Butterworth, London, 1960.

Good mathematical models for simulating the steam behavior in a turbine in its entire operating domain are not readily available, especially concerning periods in which the main-steam pressure is near or lower than the exhaust pressure. During such periods, the fluid flow behavior is very complex because the radial component of velocity become significant as compared with the axial velocity component. The available simplified mathematical models for simulating the steam behavior during normal loading typically do not perform properly when the intake pressure is near or lower than the output pressure.

In new large steam turbines, temperature measuring devices are installed at the respective stages of the HP and LP casings. These measurements provides an indication to the operator or supervising engineer in charge whenever the blade temperature exceeds its limit. The need for blade temperature monitoring for smaller and older turbine, as well as a more practical and cost effective ways than installing temperature probes, has led to a need, herein recognized, for a practical system for estimating in real time and monitoring turbine blade temperature during operation.

The present invention is intended to be practiced preferrably with the application of a programmable computer.

In accordance with an aspect of the invention, a method for blade temperature estimation in a steam turbine utilizes measurement values including pressure and temperature at locations other than directly at the blades, principally at the input and output stages. Initially, blade temperature is simulated by using a water/steam cycle analysis program as well as by directed experiments. An artificial neural network (ANN) is trained by presenting the measurement values and the blade temp values. In a present exemplary embodiment, it is found that 4 values provide a satisfactory result. In one method the ANN is used directly to derive operating blade temp values.



In a accordance with another aspect of the invention, a hybrid approach, 5 measured values are utilized. A subset of, for example, 4 parameter values is used for training the ANN and another subset of, for example, 3 values is used for performing a calculation for another intermediate parameter. Using the intermediate parameter and one of the 5 measured values, a blade temperature is calculated.

In accordance with still another aspect of the invention, the user interface provides a real-time information display for a supervising engineer in charge of turbine operation so that critical parameter values and undesirable combinations of operating conditions are readily observed and deviations are made apparent so that corrective action can be initiated rapidly. While graph plots of parameters can be readily presented, such a format generally does not readily provide an overall picture of the state of the turbine with regard to the distribution and combination of temperature, pressure, steam wetness or superheat, and turbulence effects.

In accordance with the present invention, an overview of the operating situation is made more readily apparent by representing the operating expansion and compression processes by lines on a Mollier enthalpy/entropy chart. In combination, real-time parameter values and parameter trends are also presented. Using the Mollier chart information in conjunction with trend and real-time information, the supervising engineer can more quickly identify and correct undesirable and potentially troublesome operation conditions.

In accordance with an aspect of the present invention, a system utilizes a hybrid ANN (artificial neural network)-algorithmic based scheme for estimating the blade temperature from other measurements which are commonly available. The commonly available measurement values are herein utilized. The training data for the ANN includes both data generated by mathematical model and by experiment.

The invention will be better understood from the following detailed description in conjunction with the drawing, in which

FIG. **1** shows a windage module architecture in accordance with the invention;

FIG. **2** shows an artificial neural network based scheme for blade temperature estimation in accordance with the invention;

FIG. **3** shows a training procedure for an artificial neural network in accordance with the invention;

FIG. **4***a* to **4***d* shows graphical user interface structures applicable in conjunction with the invention; and

FIG. **5***a* to **5***j* shows graphical interface views applicable in conjunction with the invention.

During the operation of the steam turbine, heating due to windage must be maintained within allowable limits by the operating mode. The windage modules for HP and LP turbines in accordance with the present invention will provide the operator with an estimation of the blade temperature at the respective turbine stages. The interactive user interface herein disclosed displays the real-time value, a trend graph of these values, and the respective states within the Mollier diagram. Supervisory recommendation may be deduced from the estimation and other available measurement values.

In the following, examples of the windage phenomenon are given. In the HP turbine, as there is no steam flow through the turbine following a trip, the extent of energy transfer depends on the pressure and the steam density in the turbine. At a full load trip, the corresponding high cold reheater pressure will initially be present. In order to avoid impermissible heating by windage losses, an adequate pres-

sure decay or a certain cooling steam flow is required. The expansion lines in the Mollier diagram indicate the advantage of a sufficient HP turbine flow after full load rejection to zero load. The operator is much better informed by such a figure.

On-line visualization of the expansion/compression lines is especially beneficial for other parts of the turbine which are subject to overheating, due, in the present particular case, to the windage phenomenon. For heating steam turbines when the control valves, for example, in the cross over line for the two lower heaters are closed, the LP turbine requires cooling steam to hold within permissible limits the temperature rise caused by windage in the last stage. In this operating mode, the steam in the LP turbine absorbs energy resulting from the windage losses which predominate significantly within the last stages.

In general the windage module will follow the system architecture used in a system known as the DIGEST system. DIGEST is a modular monitoring system for power system plant developed by the KWU-FTP activity of Siemens Aktiengesellschaft, (Simens AG), a corporation of Germany. DIGEST features a modular system architecture which can be divided into six different levels which will be explain briefly below. The module components are written in C, with much flexibility in building any structure of choice.

The proposed windage module system architecture is shown in FIG. **1**. The first two levels are already available as part of DIGEST. Modifications were done to the administrative and data levels. Modifications in both the communication and data levels include parameter specification which is needed for requesting the module-specific data through the data bus,and for creating the data server and data base. The main windage module development is done mainly at the action and presentation levels.

As indicated in FIG. **1**, the six levels in the windage module are:

1. Acquisition level. This level manages the data acquisition process, which comoprises several programmable logic controllers (PLC) **2** of the type Siemens Simatic **5**. Documentation on Simatic **5** is available from Siemens Industrial Automation. Its capabilities include signal sampling, A/D conversion, limited computation, executing sequence process action, cycle timing, and open communication functions. It is used in this context as a data acquisition device where it samples the measurement data at a predetermined rate, digitizes it and transfers the data through the ethernet network asynchronously.
2. Communication level. This level basically is the communication server **6** which manages the transfer of information between the network and the DEC (Digital Equipment Corporation) digital workstation machine (s). The standard DEC module that handles the communication issue is called Omni-Server/DECnet PhaseV. The processes within the DEC which manage the the data transfer are indicated by DEC-S**5**, **8**, and S**5**-DEC, **10**. DEC-S**5** manages the data transfer from the adminstrative level to the S**5**, and S**5**-DEC manages data transfer from the S**5** to the adminstrative level.
3. Adimistration level. An administration level of control handles the data request from the windage process control by propagating the request in the right format to a communication level, which is done by a telegram distributor module **12**. It also manages the incoming data in a certain format and forwards the data back to the process control for storage. This is done by a telegram receiver module **14**. Other functions include managing the buffer capacity (de-log), **16**, self checking process (watch-dog), **18**, and several timers/clocks for interrupt purposes (time-control), **20**. Self checking process is mainly to check the status of all processes within the system, and re-boot the system if necessary.
4. Action level. The action level controls the continuous background process and computation. These include the initiation of data request (sending RQTs), management of incoming data (RDTs), data storage, all computation processes, and storage of results. A more detail description of this level can be found in the next section. This level may also include the output management which test the validity of the computation result. In this scheme the results of the hybrid artificial neural network (ANN) estimator are always compared to the result of the analytical module. This verification is required to detect possible bad results which are usually caused by input values which are far away from all samples that had been presented during the ANN training period. Large discrepancies may indicate that further re-training is in order.
5. Data level. The data level handles all processes concerning data storage and access. It includes the data server **22** and data base **24**. All access to the data base must be done through the data server **22**. Once the data is stored in the right format into the database **24**, it can be accessed easily by all levels.
6. Presentation level. The presentation level provides a graphical user interface which allow the users to view all the necessary information in several different fashions, that is, current values, trend diagram and Mollier diagram. It consist of the Windage Graphical User Inteface **26**, Free Graphics **28**, and shared memory **30** for storing the intermediate parameter values needed for the user interface. The free graphics is an independent graphical tool for plotting any parameter values stored in the data base. This tool is developed as a part of the original DIGEST system.

The information is presented in several layers starting with the main windage screen which will mainly show the blade temperatures. The subsequent layers will show the detail conditions for each turbine section. These layers will provide information on all parameter values which are relevant to the operator for making appropriate decisions concerning the turbine operation. Further detail on the process within this level is provided in the following sections. detail in the next section. A development screen is optionally provided for accessing some internal module and system parameters or processes; however, principally because of security reasons, this feature may preferrably be omitted in an actual working version.

The monitoring process may not always be necessary to cycle at the same rate at all times; it should depend on the turbine operating conditions. Several scenarios can be predetermined for each specific turbine. For example, no load, full load, and low load during slow shutdown, start-up, and load rejection. The monitoring cycle should be adjusted automatically for different conditions, depending on their criticalities, and the respective display may be arranged to pop-up to assist the operator.

The windage module basically has two main processes, the background process and the interactive display process. The background process is responsible for obtaining the necessary parameter values, calculating the blade temperature at a predefine rate, and recording the relevant information into the appropriate shared memory and data base. The interactive display process will show the necessary or

requested information graphically at any point of time. The process rate is limited by the minimum amount of time required before all measurements stabilize, and will vary based on the severity of the turbine condition. Operation near the critical blade temperature may require faster process rate.

Before the monitoring process, the ANN must be trained. The training sub-structure is responsible for producing the appropriate weights and parameters that will be used in the monitoring module. This process is done off-line and is not controllable through the GUI interface. The network is trained using the simulated data obtained by computing the estimated temperature using the analytical means for the expected normal operating domain, and actual data obtain from field experiments. The experiments concentrate on generating data in specific low steam flow conditions, such as shutdowns, loss of loads, and start-ups. This arrangement is expected to be able to estimate the blade temperature for the entire turbine operating ranges. Minimal inputs to the estimator are the real-time measurement values of the pressure of the main steam, temperature of the main steam, pressure of the third stage and exhaust pressure. Additional inputs can be optionally provided and evaluated.

The background process will obtain measurement data, calculate the blade temperature and other necessary values, and store those values in appropriate locations. The process sequences are as follows:

Request the necessary measurement data to Acquisition Level through the Communication (using DEC-S5 protocol) and Administrative Levels (telegram distributor).

Receive measurement data from data acquisition system Simatic **5** (Siemens PLC). The request is propagated through the ethernet network, communicated using the S5-DEC protocol, and managed by the tele-capture within the admistrative level. The list of the measurement parameters include:

Pms=Pressure of main steam (bar),

Tms=Temperature of main steam (°C.),

P1=Steam pressure before blading (bar),

T1=Steam temperature before blading (°C.),

P3=Pressure at the third stage

Pex=Exhaust pressure after reheater (bar)

Peh=Exhaust pressure before reheater (bar),

Teh=Exhaust temperature before reheater (°C.),

Tcb=Bottom casing temperature (°C.),

Tcu=Upper casing temperature (°C.),

Tci=Inside casing temperature (°C.),

Tco=Outside casing temperature (°C.),

N=Rotational speed (RPM)

Pout=Output power (MW).

Preprocess incoming data into the desired format (interpreter). This process basically reads the incoming data string and reformat it to a standard ASCII format.

Store data in the intermediate files for futher processing.

The estimator will calculate the blade temperature value using the measurement values. The input measurment values used for estimating the blade temperature, at least for the HP turbine, are:

1. Pressure of the main steam (Pms),
2. Temperture of the main steam (Tms),
3. Pressure at the third stage (P3rd), and
4. Exhaust pressure (Pex).
5. Rotational speed.

One approach directly estimates the blade temperature using a straightforward **3** layer ANN, FIG. **2** (*a*). The second approach uses a hybrid technique, FIG. **2**(*b*) by decomposition of the intermediate parameters, where:

a. One intermediate parameter (**T3**) is calculated analytically using

$$T_3 = \frac{T_{ms}}{\left(\frac{P_{ms}}{P_3}\right)^{\frac{n_0-1}{n_0}}} \quad \text{Eqn. 1}$$

where $n_0$ is a given constant related to a specific turbine size.

b. Another intermediate constant (n) will be calculated by the trained ANN based on the current input values.

c. Using the two intermediate values, the current blade temperature is then calculated using the equation Equation 2 below.

$$T_{blade} = \frac{T_3}{\ln\left(\frac{P_3}{P_{ex}}\right)^{\frac{n-1}{n}}} \quad \text{Eqn. 2}$$

In this manner, a separation is maintained between the (mathematically) unknown model from the known model. In this manner, the complexity and nonlinearity within the "black box" ANN model is reduced. Moveover, this also helps in reducing the ANN model dependence on specific turbine parameters. This improves the accuracy and robustness of the overall estimation scheme, including generalization between different turbines. This allows the method to retain flexibility such as in the alteration of intermediate parameters in the light of new knowledge, which also applies to input parameters. Such adaptability is herein contemplated.

The blade temperature estimation and other measurement parameters are then stored in two different places: the Data Base and intermediate Shared Memory.

a. All values are stored in the Data Base through the Data Server

b. Values needed for display within the GUI are also stored in a temporary Shared Memory.

These values are then available for reading by the GUI process.

FIG. **3** shows the general traning process which applicable to the ANN-module either in the direct approach or the hybrid approach. The only difference is in the input-parameters as indicated in the background process. The process can be described as follows:

The first step is data construction which basically combines the data obtained from simulation using water/steam cycle analysis and data obtained from the experiments. Such analysis is for example included in thermodynamics modules within the DIGEST system. The water/steam cycle analysis is used inside the themodynamic module in the DIGEST system. As has been explained, the DIGEST monitoring system is currently available in the market through SIEMENS AG.

Next, the data is re-formatted such it matches the input format of the ANN. The data is then reorganized by separating the data into two separate data files where one is used for training and validation purposes, and one for testing purposes. Although there is no certain rule for regrouping the available data, data should be reorganized such that all

operating regions should be well represented. In accordance with the present exemplary embodiment, 80% of the available data is utilized for training and validation and the rest for testing.

The ANN structure is a standard multilayer, with 1 hidden layer. The number of hidden units may vary from 4 to 10 without significant improvement in performance: a longer traning period is needed for larger number of hidden units, and it may run the risk of overfitting.

In reference to FIG. **3**, starting with an initial set of traning parameters, including type of optimization algorithm, type of activation function, number of hidden units, error thresholds, the training process is started. The optimization algorithm used is a standard technique available in various optimization or Neural Network textbooks. See, for example, Hertz, A. Krogh, and R. G. Palmer, "Introduction to the theory of neural computation", A lecture notes volume in the Santa Fe Institute Studies in The Sciences of Complexity, Addison-Wesley Publishing Company, July 1991; and D. Rumelhart, J. L. McClelland, and the PDP Reseach Group, "Parallel distributed processing: Exploration in the mocrostructure of cognition, Volume 1: Foundations", MIT Press, Cambridge 1987.

Several techniques were investigated in conjunction with the present exemplary embodiment, including gradient descent, and few conjugate gradient techniques. Faster convergence is obtained by applying the one variation of conjugate gradient techniques.

If the system satisfactorily converges such that the validation error thresholds are satisfied then the ANN parameters (connection weights and unit's threshold values) are stored for testing. If the system does not converge, then the training parameters must be modified until a solution is obtained.

The processes above may be done repeatedly since it is generally known that the system may converge to different solution with different initial condition and training parameters. Obtaining siginificant number of solution may increase the possibility finding the global optimal solution

The solutions are then tested using the data test file. The solution with the smallest error will be used in the estimation process during the background processl.

In addition to the current values and trend diagrams, the graphical user interface will also able to show the turbine conditions within the steam behavior Mollier diagram. This diagram, also called a Mollier chart, entropy/enthalpy diagram, or a total heat/entropy diagram, serves as a familier environment for any thermodynamics engineer and a better representation of the turbine condition with respect to all known critical operating boundaries. Therefore, this on-line turbine condition visualization will better help a user in taking appropriate control actions.

Generally the GUI process must be initiated by the user. It will access values stored by the background process as required. The GUI process follows the following steps (see the correponding illustration in FIG. **4**).

The Windage Graphical User Interface Module can be initiated independently or from within DIGEST. This will automatically initiate the connection to the Shared Memory unit. The shared memory unit is basically a routine which manages the access and transfer of data between the GUI and any process outside it, which mainly includes a buffer.

From the front page, FIG. **5**(*a*), the user can select, through the 'TURBINE' menu, so as to view any of the following turbine windows:

HP turbine,

LP**1** turbine,

LP**2** turbine,

or any other turbines (of applicable).

For each turbine, there are three view windows that can be selected through the 'DIAGRAM' menu:

turbine overview (FIGS. **5**(*b*)–**5**(*d*),

mollier diagram (FIGS. **5**(*e*)–**5**(*g*), or

trend diagram window (FIGS. **5**(*h*)–**5**(*j*).

The 'turbine overview window' gives the current value of the blade temperature, as well as other information which may be important for the user to make any decision concerning the control of the turbine.

The Mollier diagram is generated based on the standard thermodynamic calculation available on any thermodynamic text book such as the afore-mentioned books. A routine is herein used which will generate the background Mollier grid, and then overlay the expansion data which are calculated from the current measurement values on top of the grid. For example, such a routine is available from Siemens AG in VISUM, a user manual, Version 3, October 1992.

Several features which built into the Mollier diagram window include:

1. Capability to zoom within the enthalpy-entropy graph just by creating a box with the mouse enclosing the desired region.
2. Instant mini trend diagram, which can be activated by clicking at the correponding parameter value table/box.
3. Mollier option interface, provide ways to personalize the viewing parameters to the user preferences. It also provide temperature thresholding which allow the user to set a certain threshold for activating the warning label and sending an alarm signal to the operator.

The trend diagram allows the selection of up to ten parameters to be shown at the same time. The maximum number of parameters that can be shown is essentially unlimited; however, any number larger than ten will cause difficulties in viewing the graph itself. It has the same feature as feature #2 in the Mollier diagram. The exact value within a graph can be found by clicking on the desired point. The exact value will be displayed under the corresponding axis.

From the trend diagram window, the user can further analyze the data by selecting the 'FREE GRAPHICS' which will give the user access to the complete data base. This component is provided within the DIGEST system.

The GUI display process will access the necessary data from the Shared Memory, with the exception of the FREE GRAPHICS routines which will access data from the data base through the data server.

While the invention has been described by way of exemplary embodiments, various changes and modifications will suggest themselves to one skilled in the art who becomes familiar with the invention. For example, the choice of parameters made herein can be changed as a matter of choice or convenience. These, and like changes are contemplated to be within the scope and spirit of the invention which is defined by the claims following.

What is claimed is:

**1**. In a system for monitoring steam turbine blade temperature utilizing measurement parameter values, a graphical user interface utilizing a computer for displaying a menu so as to allow selection for viewing of any of the following turbine diagram windows:

turbine overview;

HP turbine;

LP**1** turbine;

LP**2** turbine;

any other turbine included within the system;

wherein for each turbine, view windows selectable through said menu are provided, including: turbine overview, actual on-line turbine condition on a Mollier diagram, and a trend diagram window;

said turbine overview window displaying a current value of blade temperature; and

said Mollier diagram and said actual turbine condition on said Mollier diagram being generated automatically by said computer based on thermodynamic calculations and blade temperature estimation by a hybrid artificial neural network.

**2**. A graphical user interface in accordance with claim **1**, wherein said turbine overview view window displays other information deemed important for a user in making a decision concerning the control of said turbine.

**3**. A graphical user interface in accordance with claim **1**, wherein said trend diagram view window allows the selection of up to ten diagrams.

**4**. A graphical user interface in accordance with claim **2**, wherein said Mollier diagram is generated by said computer utilizing a routine which will generate a background Mollier grid, and then automatically overlay real time data derived from measurement parameter values and blade temperature utilizing said estimation by a hybrid artificial neural network.

**5**. A graphical user interface in accordance with claim **2**, wherein said trend diagram view window allows the display of an exact value at a desired point within a graph by clicking on said desired point, whereby said exact value will be displayed under the corresponding axis.

**6**. A graphical user interface in accordance with claim **2**, wherein said trend diagram view window allows a user to further analyze data by selecting 'FREE GRAPHICS' which will give access to the complete data base.

**7**. A graphical user interface in accordance with claim **4**, wherein said Mollier diagram view window has the capability for any and all of:

zooming within the enthalpy-entropy graph just by creating a box with the mouse enclosing the desired region;

displaying an instant mini trend diagram, which can be activated by clicking at the corresponding parameter value table/box;

by way of a Mollier option interface, providing user options to personalize viewing parameters; and

providing temperature thresholding which allows a user to set a certain threshold for activating a warning label and sending an alarm signal to an operator.

**8**. A graphical user interface for providing a real-time information display for a supervising engineer in charge of turbine operation so that critical parameter values and undesirable combinations of operating conditions are readily observed and deviations are made apparent so that corrective action can be initiated rapidly, said interface providing an overview of an operating situation, made more readily apparent by representing operating expansion and compression processes in real time by lines automatically generated on an automatically generated Mollier enthalpy/entropy chart based on thermodynamic calculations and blade temperature estimation by a hybrid artificial neural network, together with real-time parameter values and parameter trends.

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